ATOMICS

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By ANDREW W. KRAMER

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A bi-monthly journal devoted to the needs and interests of everybody concerned with the application of nuclear energy in all its various phases, in industry, in the medical and biological sciences and in the development of electrical power and heat.

ATOMICS

ANDREW W. KRAMER, *Editor*

The H-Bomb. . . . As pointed out in the article on the hydrogen bomb in this issue, the construction and large scale use of these bombs, assuming they can be made to work, could well spell the twilight of our civilization. Yet, despite much discussion concerning the moral and political aspects of this bomb, it seems that we have practically no alternative but to proceed with its development, because whether we develop it or not, Russia will develop it. This, it has been pointed out, will constitute an atomic armament race. True, so it will, and even though we may be at a disadvantage in such a race, it will be better for us to be in it with all its frightful implications than not to be in it and in the end have to submit to the overwhelming force of Russian dictatorship. In such an armament race Russia will have a lead because in the kind of war that might wipe out entire cities and whole armies at one surprise attack, we would strike only if struck first. The element of surprise would always be a Russian monopoly while the exposed nakedness of America's great cities and the vulnerable concentration of her industrial plants would make the United States a far more profitable target than Russia's scattered industrial centers and cities.

With the H-bomb however, in case of a surprise attack we would have a means to retaliate, and that fact alone would make an enemy think twice before launching an attack. There are those who feel that perhaps if both sides have the hydrogen bomb, its very frightfulness will dissuade everyone from using it as has been the case with the use of poison gas. This analogy does not hold, however. Poison gas is an anti-personnel weapon; it only destroys people, not structures. That is why it has not been used in recent conflicts. Military conquest demands the destruction of industrial production centers and military defenses, and in this respect poison gas is of no use. The hydrogen bomb, on the other hand, will probably be the greatest and cheapest destructive force man has ever produced and for that reason it *will* be used.

Senator McMahon has proposed that instead of building the H-bomb that the money be spent in some other way, in an attempt to get at the people in Russia and Russian dominated countries and thus to change their attitude toward democratic nations. The proposal to

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spend, say, ten billion dollars a year for five or ten years in this manner might be able to accomplish a great deal in this direction.

This is a good proposal and it is worth trying. We have spent billions upon billions in war to little purpose—in achieving one victory we are confronted with something perhaps even worse. Rather than run the risk of another world war which would mean the end of our democratic order almost as surely as Russian domination itself, it would be worth while to spend fifty or a hundred million dollars during the next ten years in an effort to prevent such a war.

It would not be wise, however, to promote such a program *instead* of the plan to build the H-bomb. If we abandoned the H-bomb but proceeded to carry out an *educational* plan of some kind, Russia could, in a few years, when she had the H-bomb, issue an ultimatum or make an H-bomb attack even without an ultimatum. In that case, if we did not have the H-bomb, Russia would still have the winning cards.

Rather than propose one plan as an alternative to the other, we should engage in both of them. After all, if, as has been estimated, the development of the hydrogen bomb will cost anywhere between a half billion to two billion dollars, its cost will still be a small fraction of what Senator McMahon proposes to spend, hence, the cost of the H-bomb becomes relatively unimportant. The fact that we were developing the hydrogen bomb need not in any way interfere with putting a proposal such as Senator McMahon's into effect.

The vast amount of money needed for the carrying out of such a program should not deter us, indeed, expense in a situation of this kind is the least forbidding prospect. In discussing the hydrogen bomb attention has been called to the fact that even though such a bomb would be probably a thousand times more powerful than the uranium bombs, because of the cube-root law its destructive force will be only ten times as great. But, don't make the mistake of taking comfort in the cube-root law. If the H-bomb will do only ten times the damage of the uranium bomb, it will create as much radioactivity as a thousand uranium bombs. Should we explode even a moderate number of them in an atomic war, we could conceiveably so poison the earth's atmosphere as to make human survival impossible. Of course, the enemy would know this grim fact also but they might reason that if they acted quickly enough they could win control of the world by the use of only a small number of H-bombs and thus stop somewhere short of complete extinction of the human race.

No matter which way we look the prospects are dark, so it would be unwise to let our course be affected by the thought of spending a hundred billion dollars in a final effort to bring some sense into the affairs of the so-called human race.

AWK

Theoretical Aspects of the Hydrogen Bomb

Because of the great popular interest in the so-called hydrogen bomb this article is presented to acquaint readers with some of the basic factors that might be involved in the design and construction of such a super-bomb. Actual details are, of course, top military secrets but certain aspects of the basic principles involved are known from available nuclear physics data and from the recently published Seventh Semiannual Report of the United States Atomic Energy Commission

By ANDREW W. KRAMER

WHEN A SLOW neutron enters the nucleus of an atom of uranium-235, the resulting U-236 nucleus exists for only an extremely brief instant—an interval that can be measured only in hundred millionths of a second. It explodes instantly into two or more parts with terrific force—an energy release, in fact, amounting to approximately 200 million electron volts per atom. As shown in Fig. 1, in many cases the U-235 nucleus splits into nuclei of barium (Ba) and krypton (Kr) and at the same time releases one or more free neutrons. It is the release of these free neutrons that makes possible a sustained reaction since the free neutrons are capable of inducing *fission* in other U-235 nuclei. In terms of ordinary units the energy release obtained amounts to about 43 billion Btu per pound of uranium.

Curiously enough, despite the fact that uranium fission was the first nuclear reaction to be put to practical use, other nuclear reactions engaged the attention of physicists many years before the uranium reaction even became known. Uranium fission became known through the researches of Hahn and Strassman in 1938.

As indicated in other articles in ATOMICS in previous issues, as far back as 1932 J. D. Cockcroft and E. T. Walton achieved the first nuclear transmutation by artificially accelerated particles when they bombarded lithium with protons from their voltage-multiplying rectifier set in the Cavendish Laboratory. This was the, now, well-known lithium-hydrogen reaction. In the Cockcroft-Walton experiment, lithium-7 was bombarded by hydrogen (protons) giving the reaction:

$$ {}_1H^1 + {}_3Li^7 \rightarrow ({}_4Be^8) \rightarrow {}_2He^4 + {}_2He^4 \qquad (1) $$

that is, the combination of a lithium nucleus and a proton results in the formation of a compound nucleus of $_4Be^8$ (beryllium) which immediately splits into two helium nuclei.

The actual quantities involved in this reaction are of interest so let us examine the bookkeeping. First, consider the atomic weights of the three nuclei involved in the process. These are as follows:

Element	*Symbol*	*Atomic Weight*
Hydrogen	$_1H^1$	1.00812
Helium	$_2He^4$	4.00389
Lithium	$_3Li^7$	7.01804

Substituting these values in equation (1), we have:

$$1.00812 + 7.01804 \rightarrow 4.00389 + 4.00389$$

Carrying out the addition, we have:

$$8.02616 \rightarrow 8.00778$$

Note, that the two sides of the expression do not satisfy each other. The sum of the atomic weights of the two helium nuclei is less than the sum of the atomic weights of the proton and the lithium nucleus. The difference is:

$_1H^1 + _3Li^7$	8.02616
$_2He^4 + _2He^4$	− 8.00778
Difference	0.01838 mass units

This difference in mass, 0.01838, is the amount of mass which disappears and which, thus, is converted into energy in accordance with the Einstein equation, $E = MC^2$.

Numerically, the 0.01838 mass unit loss seems small indeed but it is large in terms of energy because of the terms of the Einstein equation which involves C^2, that is the square of the velocity of light. According to the Einstein law, 1 mass unit is equivalent to 931 million electron volts (Mev). Therefore 1 Mev is equal to 0.00107 mass unit. In the reaction under consideration, therefore, where 0.01838 mass unit is converted into energy, the amount of energy released is:

$$\frac{0.01838}{0.00107} = 17.1 \text{ Mev}$$

In other words, when lithium is bombarded with high-speed protons in

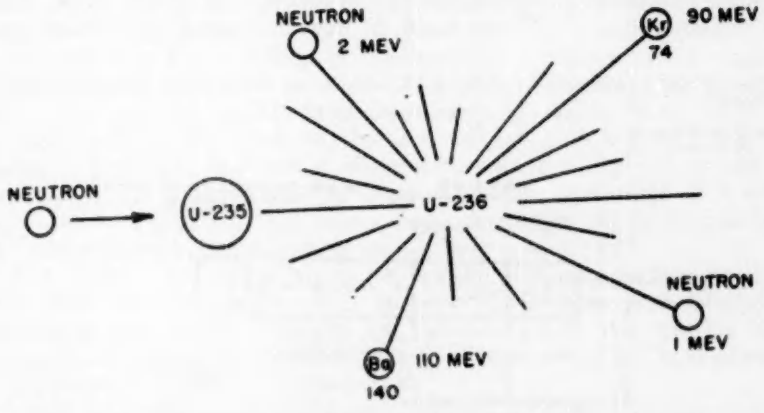


Fig. 1 When a slow neutron enters the nucleus of a U-235 atom, the resulting U-236 nucleus exists for only an extremely brief instant. It explodes instantly into two or more parts with terrific force

this manner, the resulting nucleus splits into two helium nuclei with an energy release of 17 million electron volts.

For absolute accuracy our bookkeeping is subject to a slight correction. In the beginning, a potential of 150,000 v was used in accelerating the protons. The energy required to maintain this electric potential must of course be subtracted from the total amount of energy obtained in our calculations, but it is so small that for all practical purposes it can be neglected. The 150,000 ev represents only 0.0002 mass unit.

The Cockcroft-Walton experiment, therefore, releases 17 Mev of energy with an expenditure of less than 1/100 of that energy. The experiment is of great importance because it was not only the first experiment whereby transmutation of the elements was achieved by artificially accelerated particles but it was the first known instance in which the atom was *split*. It proved the validity of the Einstein equation, and indicated that there are vast stores of energy in the nuclei of atoms that could be released by man-made apparatus.

OTHER LITHIUM-HYDROGEN REACTIONS

At first glance, the lithium-hydrogen reaction looks very attractive but in nuclear physics things are not always as simple as they seem. Offhand, and knowing what we do today, it might seem that if we could heat a mixture of lithium and hydrogen, lithium hydride for example, to a temperature equivalent to the accelerating potential used in the experiment (150,000 v) the reaction would take place spontaneously. Indeed, we would need only half that energy because two particles moving toward each other with an energy of 75,000 v would be equivalent to the required 150,000 v.

Now the temperature corresponding to an energy of 75,000 electron volts is in the neighborhood of 600 million degrees![1] This temperature is, of course, far beyond anything in our ordinary experience but it is available in the uranium fission reaction in the atomic bomb. The 200 Mev energy release in the uranium bomb explosion can only be expressed in terms of *thousands of millions of degrees* on the temperature scale. Thus, the explosion of a U-235 type bomb, if properly applied, might heat a mix-

[1] The temperature on the absolute or Kelvin (K) scale for any Mev value can easily be calculated by the formula:

$$T = 7.8 \times 10^9 E$$

where T = degrees K
E = Mev.

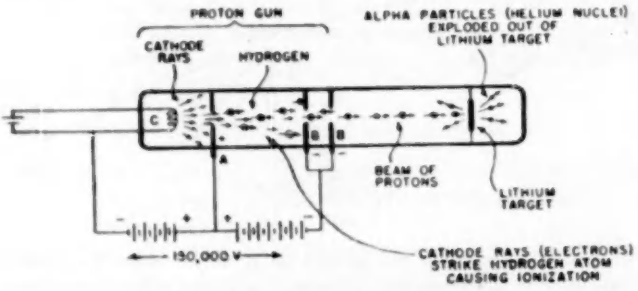


Fig. 2 The Cockcroft-Walton experiment

ture of lithium-hydride to the temperature necessary to start the chain reaction.

But, as already indicated, it is not so simple as it seems on paper, and a thorough study of the subject shows that there are hidden obstacles which may prevent this particular reaction from taking place on a large scale.

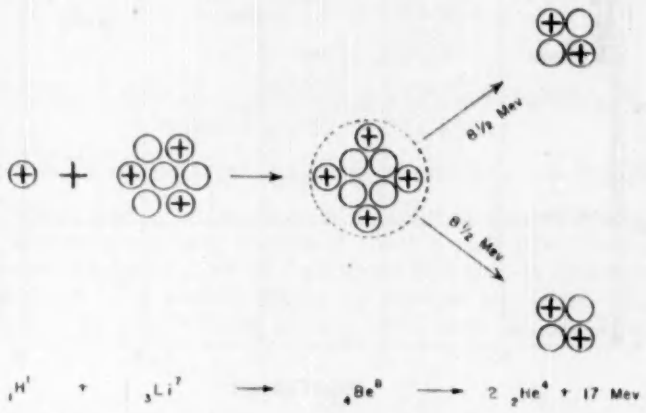


Fig. 3 This is what happens in the Cockcroft-Walton experiment

One of the reasons why the lithium-hydrogen reaction just described might not work is the fact that this particular reaction is not the only reaction possible with lithium and hydrogen. When lithium is bombarded by hydrogen it is also possible to get

$$_1H^1 + {}_3Li^7 \rightarrow {}_4B^7 + n$$

Here, the result of the bombardment is beryllium and a neutron. This reaction is endothermic, approximately 2 Mv kinetic being needed in the protons for the reaction to proceed. The excess energy of the incident protons over the 2 Mv threshold will turn in greatest part into kinetic energy of the neutrons.

As a matter of fact if lithium is bombarded by hydrogen, a great number of reactions are observed due to the fact that lithium has two isotopes, namely Li^6 and Li^7 and these isotopes react in various ways with the hydrogen nuclei. Of course, the Li^6 and Li^7 could be separated but this would be expensive and would offset the advantages the use of lithium would have if it could be used as found in nature. Actually, Li^7 is much more abundant than Li^6, the former being present to the exteent of 92.5 per cent in natural lithium against only 7.5 per cent for Li^6.

This rather detailed analysis of the lithium-hydrogen reaction has been given here for two reasons; first, to show the general method used in calculating these nuclear reaction and second because this reaction is of interest in a study of the so-called hydrogen bomb which has been so much in the limelight these last few weeks.

THE HYDROGEN-HELIUM REACTION

It has long been known that if there was some way in which we could take four protons and put them together to form a helium atom, the energy

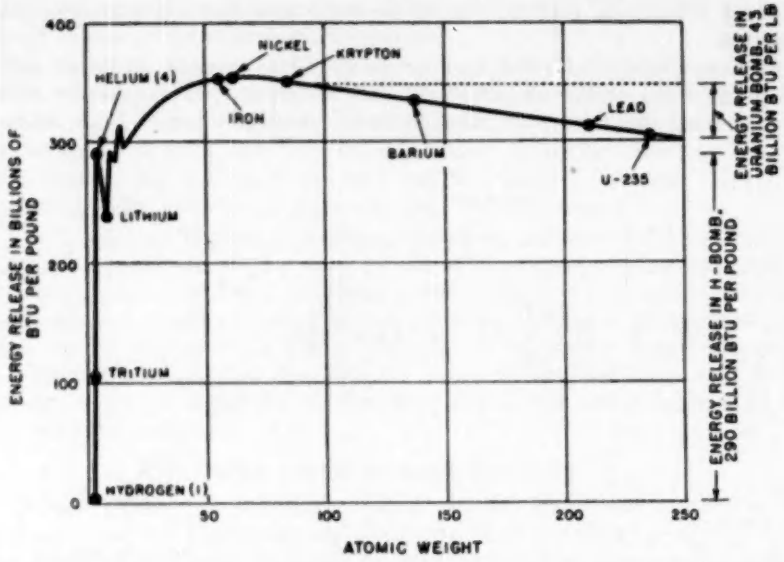


Fig. 4 Chart showing the binding energies of the elements. Atoms near the center of the periodic table have the highest binding energy. Theoretically, packing hydrogen nuclei into iron at the highest point on the curve would release the greatest amount of energy—about 350 billion Btu per lb.—but, so far, this cannot be done. Packing hydrogen into helium releases almost as much, however, and that will be the principle involved in the hydrogen bomb. Theoretically, this will release some 290 billion Btu per lb

that would be released would be exceedingly great. The nucleus of the helium atom, consists of two protons and two neutrons. Now a neutron can be thought of as a proton which has swallowed an electron.[2] Thus, if we could take four protons, make two of them to cough up the electron they had swallowed, and combine them into one nucleus, we would have a helium nucleus. Or, we might take two deuterons, which each consist of a proton and a neutron, and combine them, we also would have a helium nucleus.

Let us look at the bookkeeping.

The mass of the helium nucleus $_2He^4$ is 4.00389
The mass of the hydrogen nucleus $_1H^1$ is 1.00812
The mass of the neutron $_0n^1$ is 1.00893

Thus, the sum of the masses of 2 hydrogen nucleis is $2 \times 1.00812 = 2.01624$
and, the sum of the masses of 2 neutrons is $2 \times 1.00893 = 2.01786$
Total mass 4.03410

Thus, the binding energy of helium is:

$$4.03410 - 4.00389 = 0.03021 \text{ mass unit}$$

and since 1 mass unit is 931 Mev, the binding energy in Mev is

$$0.03021 \times 931 = 28.12 \text{ Mev.}$$

[2] See Nuclear Power Engineering, Part IX, Page 17 this issue.

The binding energy per nucleon in $_2He^4$, therefore is approximately 7.0 Mev.

Using the same method of calculation, the binding energy of the deuteron $_1H^2$ with mass 2.01470 is:

Mass of $_1H^1$ is 1.00812
Mass of $_0n^1$ is 1.00893
sum 2.01705

Binding energy is 2.01705 — 2.01470 = 0.00235 mass units, or

$$0.00235 \times 931 = 2.18 \text{ Mev.}$$

In this case, it will be noted, the energy per nucleon is only 1.09.

The binding energy of the various elements is shown in Fig. 4. The average binding energy per nucleon is about 6 to 8 Mev throughout the list of elemets except in a few of the lightest elements, as shown in the case of the deuteron. The binding energy per nucleon is greatest—about 8.7—for nuclei in the neighborhood of iron, with mass 55. As shown by the

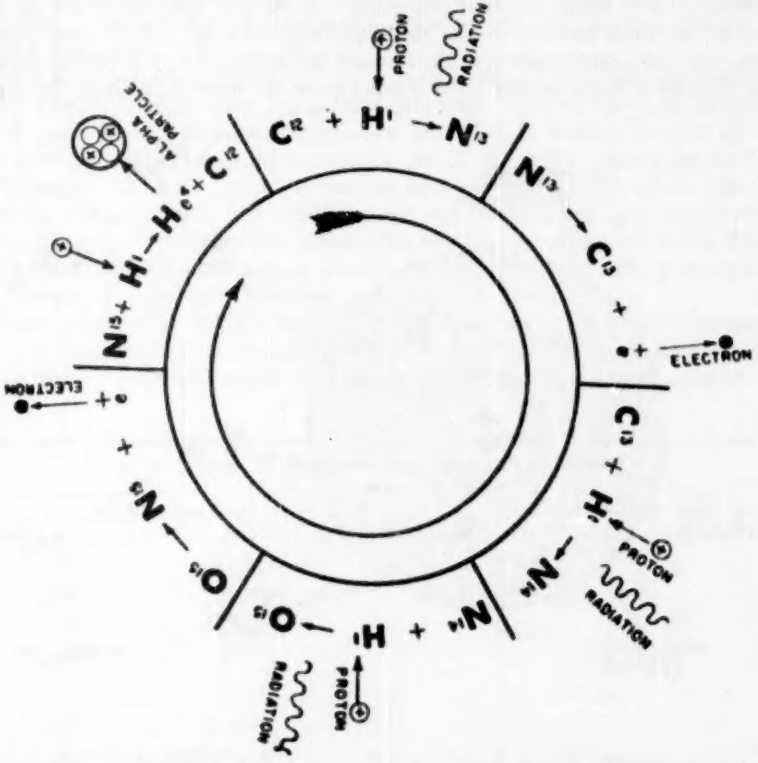


Fig. 5 Here is how helium is built up from hydrogen nuclei in the sun and also in other stars. This is the Carbon-nitrogen cycle, developed by Bethe and Wiezsaker. The carbon and nitrogen enter into alchemic reaction with hydrogen, yet do not vanish but are regenerated at the end of the cycle, serving as a sort of catalyst

curve, the energy rises steeply at the light end of the periodic table but drops off very gradually toward the heavy end. In the case of the heaviest elements, uranium, plutonium, etc., it has a value of around 7.5 Mev.

The chart shown in Fig. 4 shows why it is possible to release energy in the splitting of the heavy nuclei, such as uranium. It is possible because the nuclei near the middle of the periodic table have higher binding energies than those at the heavy end. Similarly, it shows why, at the light end of the table, energy is released by the building up of heavier nuclei from the lighter ones.

Theoretically, the greatest release of energy could be obtained from the building of nuclei in the highest part of the curve, nuclei of iron and nickel, from simple hydrogen nuclei. So far this has not been possible but if hydrogen can be packed into helium nuclei it will be possible to realize almost much, some 290 billion Btu per pound. This energy, it will be noted is much greater than that obtainable in the fission of a heavy element such as uranium into barium and krypton. In the latter process the energy release is about 43 billion Btu per pound.

This possibility of releasing energy by building nuclei from lighter ones has intrigued physicists ever since the mathematics of the processes became known. It was suspected that the energy of the sun was the result of such nuclear reactions because in the sun temperatures exist which could sustain these reactions spontaneously. As already indicated, if a mixture of lithium and hydrogen were heated to a temperature of some 6 million degrees it

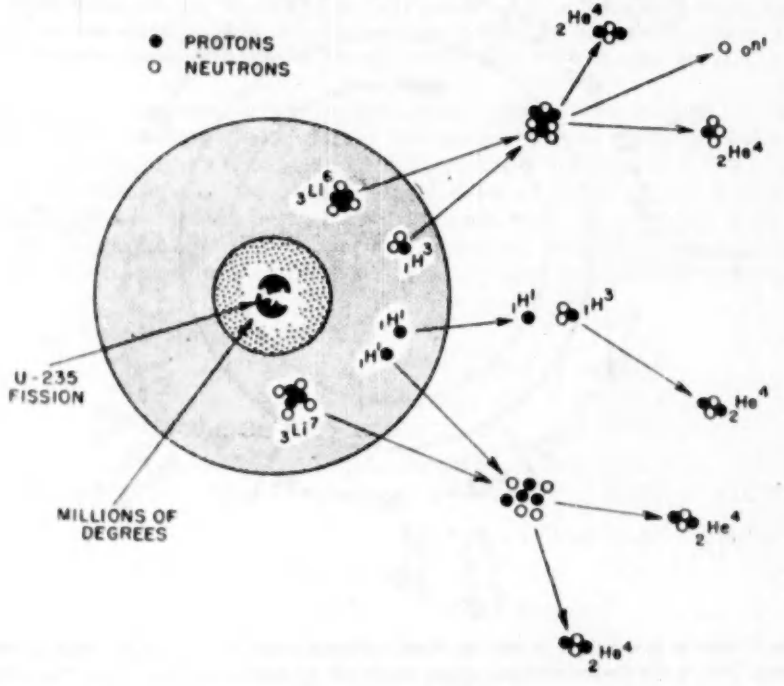


Fig. 6 Diagram showing the principle of the hydrogen bomb

would, in certain cases, result in the production of helium with an energy release of 17 Mev.

THE CARBON-NITROGEN CYCLE IN STELLAR PROCESSES

Close study of the problem, however, indicated that the lithium hydrogen reaction was not the one responsible for the sun's heat because that reaction at the central solar temperature of 20 million degrees would be too fast. All the lithium and hydrogen in the sun would be transformed into helium in a few seconds, and the energy liberation would take the form of a tremendous explosion. It was quite evident that the solar energy release was due to another type of nuclear reaction. The lithium hydrogen reaction was too fast.

Now, it was known from spectroscopic studies and from other theories of solar constitution that the body of the sun is composed of some 35 per cent hydrogen; also, that it contained a large amount of helium. Was the hydrogen-helium reaction responsible for the sun's energy?

The answer to this question was arrived at simultaneously and independently by two physicists, by Dr. Hans Bethe of Cornell in this country and by Dr. Carl von Weizsacker in Germany, in 1938. It proved to be a hydrogen-helium reaction but it is not limited to a single nuclear transformation. As mentioned previously, things are not always simple in nuclear reactions.

The thermonuclear process of the sun consists of a whole sequence of linked transformations forming a reaction chain. One of the most interesting features of the sequence reaction is that it is a closed circular chain, returning to the starting point every 6 steps. Another interesting fact in the process is that the nuclei of carbon and nitrogen which enter into an alchemic reaction with the hydrogen do not vanish, but are regenerated again through a very peculiar process known as the carbon-nitrogen cycle. The carbon and nitrogen act as a sort of catalyst to effect the transformation of four protons into a helium nucleus.

In explaining this cycle, it must be understood that it is possible to make a list of the various alchemical reactions which might be responsible for stellar energy production and to show the time needed for each reaction to

The mean reaction times for various nuclear transformations under the conditions at the interior of the sun. (Temperature, 20,000,000 K)

Nuclear reaction	Mean reaction time
$_3Li^7 + {}_1H^1 \rightarrow 2\ {}_2He^4$	1 min.
$_4Be^9 + {}_1H^1 \rightarrow {}_3Li^6 + {}_2He^4$	15 days
$_5B^{11} + {}_1H^1 \rightarrow 3\ {}_2He^4$	3 days
$_6C^{12} + {}_1H^1 \rightarrow {}_7N^{13}$	2.5×10^6 years
$_7N^{14} + {}_1H^1 \rightarrow {}_8O^{15}$	5×10^7 years
$_8O^{16} + {}_1H^1 \rightarrow {}_9F^{17}$	10^{12} years
$_{17}Cl^{37} + {}_1H^1 \rightarrow {}_{18}A^{38}$	2×10^{25} years
$_2He^4 + {}_2He^4 \rightarrow {}_4Be^8$	10^{15} years
$_3Li^7 + {}_2He^4 \rightarrow {}_5B^{11}$	3×10^{13} years
$_6C^{12} + {}_2He^4 \rightarrow {}_8O^{16}$	2×10^{38} years

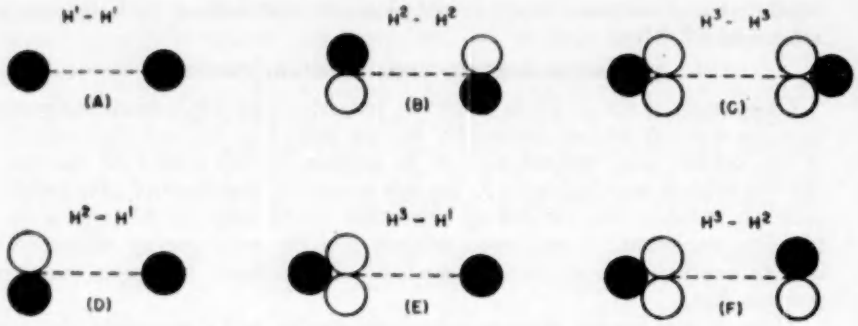


Fig. 7 The combination of the three isotopes of hydrogen, H-1, H-2, and H-3, make possible six different molecules

run halfway under conditions existing in stellar interiors. Such a list is shown in the accompanying tabulation, compiled by Dr. George Gamow from calculations made by Bethe.

The carbon-nitrogen cycle is shown in Fig. 5. As shown by the tabulation, when a carbon nucleus fuses with a hydrogen nucleus, it produces the nitrogen isotope $_7N^{13}$. It is possible to perform this union in the laboratory by bombarding carbon with a steam of fast protons. The nitrogen-13 nucleus so formed is unstable and by emitting a positive electron transforms itself into a nucleus of stable but rare isotope of carbon-13 ($_6C^{13}$). The mean time for this transformation is about ten minutes.

These stable heavy carbon isotope nuclei exist until they are hit by another proton. The capture of this proton, increases both the weight and the charge of the nucleus by one unit, thus converting it into a nucleus of ordinary nitrogen with atomic weight 14.

In time, this nitrogen nucleus captures a third proton, turning it into a nucleus of oxygen 15. Oxygen 15, however, is again unstable and in two minutes it becomes a nucleus of stable nitrogen 15 by the emission of another positive electron. Since nitrogen 15 is stable these nuclei move around the interior of the star until, once again, they encounter a proton.

Now an interesting thing happens, and this can be proved by laboratory experiment. If the fourth proton were captured by the nitrogen 15 nucleus as its three predecessors were, the result would be the nucleus of oxygen 16, that is, ordinary oxygen. The energy liberated in the capture of the fourth proton, however, sets the compound nucleus of oxygen 16 in such a state of agitation that it immediately breaks up into two unequal parts. The small part is the helium nucleus, and the remaining part is the nucleus of ordinary carbon ($_6C^{12}$) *with which the cycle began.*

Thus, it is seen that four protons captured successively by a carbon nucleus (with two of the protons turning immediately into neutrons), are re-emitted at the end of the cycle in the combined form of an alpha particle, that is, a helium nucleus. This is a most remarkable reaction. As Dr. Gamow points out, the carbon nucleus comes out of the reaction unchanged, like the Phoenix from the ashes, and its role consists only in helping, or catalyzing the transformation of hydrogen into helium. Not the least astonishing fact about the reaction is the time element; it takes six million years to complete the cycle. It is obvious, therefore, that while this slow

process is quite practicable in stellar phenomena it is far too slow to be of any direct use to us on earth.

Knowledge of this process, nevertheless, reveals a number of interesting facts. If we consider the reaction up to the point just before the addition of the fourth proton, it will be seen that the three protons two of which have changed into neutrons, constitute, what is known as tritium, that is the nucleus of the isotope of hydrogen with atomic weight 3. This nucleus consists of 2 neutrons and 1 proton. Now, about 99.7 per cent of the 6 million year period is required to hook this tritium nucleus on to the carbon nucleus. This leaves only 0.03 per cent to hook the fourth proton on to make the helium nucleus. Even this amounts to 1800 years.

TRITIUM

Tritium, however, is an extremely interesting isotope, and there may be ways of using it in a hydrogen-helium reaction under certain conditions, without the need of the carbon nucleus.

The Seventh annual report of the Atomic Energy Commission released recently, reveals for the first time that studies with tritons (the nucleus of the tritium atom) are being carried out at the Argonne, at Los Alamos and other AEC laboratories, and that "important information has been gained."

In a series of experiments with a Van de Graaff generator, tritium was bombarded with high-energy protons. In one of these reactions the resulting combination became an excited alpha particle which converted itself into a stable state by emitting radiant energy in the form of a 20,000,000 volt gamma ray.

In a second reaction observed, the proton and triton split into a neutron and the nucleus of helium 3 (2 protons and a neutron). This latter reaction was of interest because it proved reversible; that is, helium 3, bombarded with neutrons, yielded protons and tritons.

In still other experiments, deuterons were bombarded with tritons, and tritons with deuterons, to study reactions in which these two particles first combine, and then split into an alpha particle and a neutron.

It is because of the knowledge gained in these experiments and studies that AEC scientists now feel that the hydrogen-helium reaction can be made to work in an atomic bomb. Of course, a necessary concomitant is a temperature requirement of millions of degrees but such temperatures are now available in the explosion of a uranium bomb. Ever since the explosion

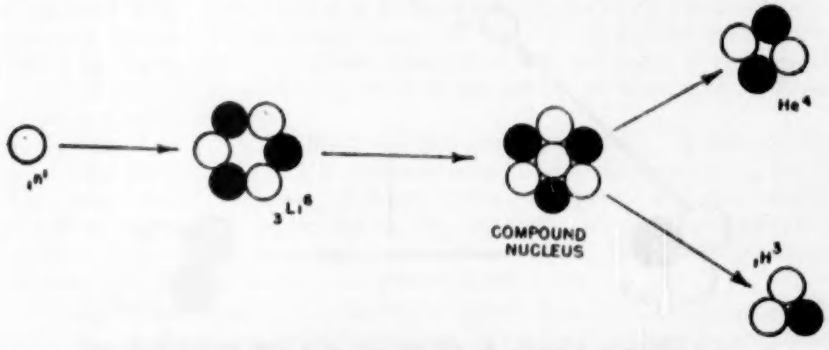


Fig. 8 Bombarding lithium 6 with neutrons yields tritium and helium

of the first uranium bomb at Alamogordo, the hydrogen bomb has been a possibility.

The design of such a bomb will probably not be easy and just what ingredients will be used and in what proportion will be a top military secret, but as indicated above enough of the general principles are known to make competent physicists confident that a hydrogen-type bomb can be made.

Tritium, undoubtedly will be a principal ingredient, and also deuterium. The latter will be a convenient source of reactive protons and neutrons. As indicated earlier in this article, the binding energy of deuterium is low, only 2.18 Mev, hence it splits easily into protons and neutrons. Lithium also has interesting possibilities, not necessarily because of the lithium-hydrogen reaction described earlier in this article but as a means to hold tritons, in the form of lithium hydride. The hydrogen isotopes which enter into these reactions are thin gases, consequently difficult to package but when combined with lithium in the form of lithium hydride they are easy to handle in a single chemical compound. Other methods will probably be used to pack more hydrogen isotopes around the uranium bomb.

BASIC PRINCIPLES OF A HYDROGEN BOMB

Thus, we begin to see what shape the so-called hydrogen bomb will take. In the center, serving as an igniter, will be a *conventional* uranium or plutonium type of bomb. Around this will be packed *any amount* of hydrogen isotope material, in combination with lithium or perhaps in some other way. Liquid hydrogen could be used but this probably would introduce insurmountable difficulties.

A combination of the three isotopes of hydrogen, namely, protons, deuterons, and tritons, the AEC report says makes it possible to obtain six kinds of hydrogen molecules as follows: Molecules composed of 2 protons, 2 deuterons, 2 tritons, a deuteron and a proton, a triton and a proton, and a triton and a deuteron. These six molecules are shown in Fig. 7.

Under proper high temperature conditions, that is, temperatures of millions of degrees, these six molecules probably will enter into a number of high energy nuclear reactions. The 2 deuteron molecule, shown at (b) for example has within its own molecular structure the necessary components of a helium atom. If such molecules could be made to collide with each other at high enough energies, it is possible that the desired hydrogen-

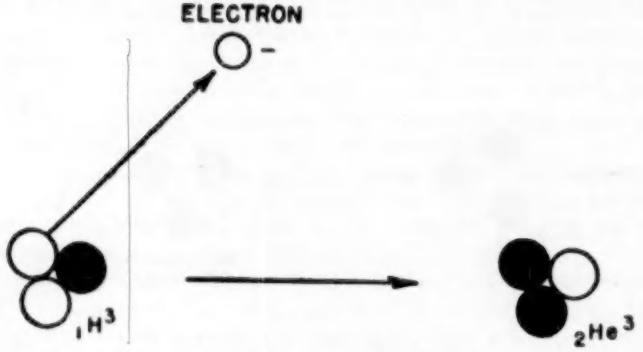


Fig. 9 Tritium is unstable. By the emission of a beta particle from one of the neutrons, it changes into helium 3

helium reaction will take place. Similarly, the 2 triton molecule, if given sufficient velocity so that in collisions the two tritons would be driven together, the result would be a helium nucleus plus two neutrons. These neutrons might carry away the excess nuclear energy and at the same time serve to promote other nuclear reactions. Many other reactions are possible from various combinations of the six molecules formed by the three isotopes of hydrogen.

In a bomb constructed along these lines, when the uranium is suddenly brought together to form a supercritical mass, it explodes, creating a temperature of millions of degrees. The whole mass of mixed or layered ingredients will be converted into a welter of speeding zigzagging nuclei, shot through with neutrons and high energy gamma rays. With proper design, many of the collisions will form helium, with each helium nucleus contributing some 28 Mev to the total explosive force.

The energy released by such a bomb can be about anything we wish to imagine. The hydrogen bomb has been referred to as having 1000 times the power of the uranium bomb. Whether this estimate be too large or too small, theoretically there should be no limit to the energy released by such a bomb since it will be a function of the quantity of hydrogen involved. In the case of the uranium bomb, the power is dependent upon how large a supercritical mass of U-235 or Pu-239 can be brought together before it blows itself apart. In the case of the hydrogen bomb, there is no *critical* mass involved. There need be no limit in this respect. Theoretically any size mass could be exploded and it would be possible to explode a whole ship full of hydrogen in an unsuspecting enemy's harbor.

Of course, the efficiency of the reaction, would be extremely important. Attention was directed earlier in this article to the two types of lithium-hydrogen reactions, one being endothermic and the other exothermic, depending upon the incident energy of the bombarding proton.

Since tritium will obviously be an important ingredient of the proposed hydrogen-type bomb, its production will probably be the most expensive part of the project, just as the production of U-235 and plutonium accounted for nearly all of the two billion dollars spent in developing the atomic bomb.

Tritium has become available only recently. While it is excessively rare in ordinary hydrogen, it is not too difficult to make, and small quantities for experimental use have been made at the Argonne Laboratory since September 1948. One method is to bombard lithium 6 with neutrons in a uranium reactor. The reaction, shown in Fig. 8 yields tritium and helium, which can be separated by simple chemistry. This job could be done in the Hanford plutonium producing reactors but special reactors will no doubt be built for this purpose.

Tritium is unstable, and has a half-life of about 12 years. By the emission of a beta particle one of the two neutrons changes into a proton, and it becomes helium 3, an isotope of helium with two protons and one neutron, which occurs in natural helium in the proportion of about one part in a million. This isotope is notable because it is the only known stable atomic nucleus which contains more protons than neutrons.

There is one aspect of a hydrogen bomb that has a bearing on the efficiency of the uranium bomb reaction. As is well known, in the fission of U-235 or Pu-239 a great deal of the fissionable material is scattered by

the explosion before it can react. This greatly lowers the efficiency of the reaction. In a hydrogen bomb, however, the ingredients packed around the uranium core could be induced to generate large numbers of free neutrons. These would make more of the uranium react, thus stepping up the efficiency of the core's explosion.

The whole subject of the hydrogen bomb is extremely intriguing to scientists but its significance to the human race must be viewed with apprehension. For make no mistake about it; this development is one which could indeed spell the twilight of our civilization. In the words of Dr. Kral Darrow, "We speak of an awful headache, a dreadful cold, an appalling storm, and now when something comes along that is really awful and dreadful, frightful and appalling, all these words have been devaluated and have no terror in them. I have to fall back on the saying, of unknown origin and dubious value, that the strongest emphasis is understatement. Let then, these pictures with their circles and symbols, and their numbers, be considered as an emphatic understatement of the most terrific thing yet known to man."

[END]

"Uh Uh—I won't shake hands—how do I know you ain't radioactive?"

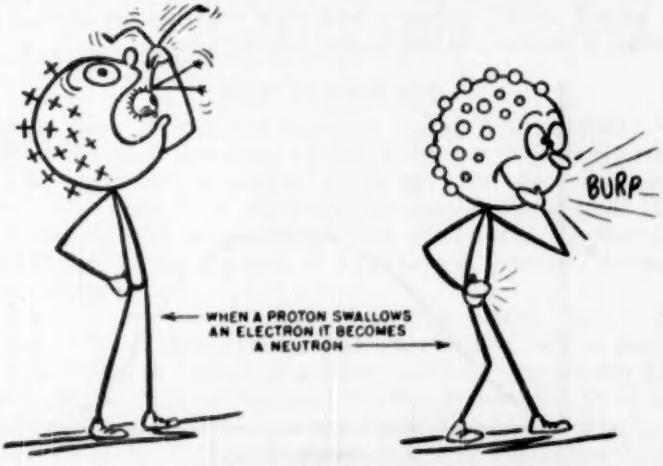
Nuclear Power Engineering

Part IX. Further considerations of nuclear Processes . . . Conversion of neutrons into protons and vice versa . . . Energy changes involved in beta radiation . . . Theory of the Neutrino . . . Relation of neutron velocity to nuclear cross section . . . Effect of resonance on cross section . . . Slow neutrons—why they are effective in inducing nuclear reactions . . . Theory of moderators . . . Different types of neutron induced nuclear reactions . . . Use of cadmium as a neutron absorber . . . Measurement of neutron absorption . . . General features of collisions.

By ANDREW W. KRAMER

WITH AN UNDERSTANDING of the fundamental principles involved in the phenomenon of radioactivity we now return to a further consideration of nuclear processes in general because these processes are alike whether they arise spontaneously in radioactivity or in man-induced nuclear reactions. The emission of a beta particle from a nucleus, for example, is the same whether it occurs naturally, as in the decay of Radium-B (Atomic number 82) into Radium-C (Atomic number 83), or in the transmutation of U-238 into plutonium by neutron absorption in a nuclear reactor. In either case it means the transformation of a neutron into a proton. That is why, when beta emission occurs, the atomic number of the nucleus steps up one. One of the neutrons changes into a proton.

A neutron can be thought of as a proton which has swallowed an electron, thus neutralizing its positive charge. Consequently, in any nuclear process in which a beta particle is emitted, one of the neutrons may be



A neutron is a proton which has swallowed an electron

thought of as ejecting the electron it has swallowed and so reverting to a proton.

When a nucleus emits a beta particle there is, of course, also an energy change in the nucleus—it goes from one definite energy state into another. This being the case, one would expect the emitted beta particle to possess a definite amount of kinetic energy. Experimentally, however, it is found that beta particles are not homogeneous in energy but have an energy distribution curve as shown in Fig. 1.

The upper limit of the energy corresponds to the value expected by the law of the conservation of energy. Several explanations for this distribution of energy have been suggested but, as yet, no completely satisfactory explanation or theory has been advanced. It might be supposed that a gamma ray is emitted during the beta emission process to account for the discrepancy in energy and, indeed, in many instances beta emission *is* accompanied by gamma radiation. Cases are definitely known, however, where no gamma radiation takes place. Yet, the beta particles emitted have different kinetic energies.

THEORY OF THE NEUTRINO

This strange behavior has brought forth the suggestion that the energy conservation law does not hold. A more acceptable hypothesis, however, is that the energy conservation law *is* valid and that part of the energy is emitted as *undetected* radiation. This radiation is supposed to consist of particles possessing extremely remarkable properties. They are assumed to be uncharged and of very small mass, hence, cannot be observed. In order to conserve angular momentum, an angular momentum of ½ quantum has been ascribed to this particle. This extraordinary particle has been named the *neutrino*.

As already explained the neutral character of the neutron permits it to approach a nucleus without having to overcome any repulsive forces. That is why the discovery of the neutron was so important. Before this discovery, all nuclear experiments were made by the use of charged particles which had to be accelerated to extremely high velocities to overcome the coulomb forces surrounding the nuclei. With the neutron, high velocities are not needed, indeed, neutrons with slow velocities are quite as effective in initiating a nuclear reaction as fast moving ones.

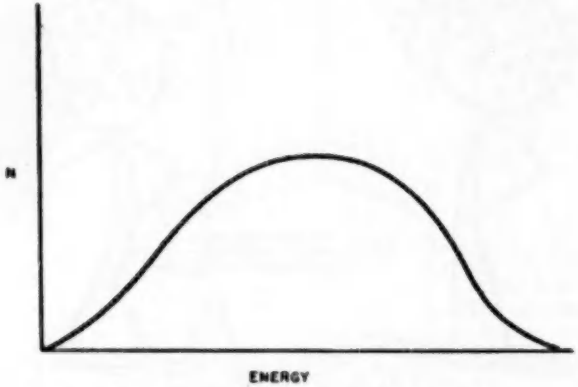


Fig. 1 Energy distribution curve of beta particles

This being so, one would expect the number of reactions to be the same for neutrons of different velocities, and if we plotted a yield curve as a function of neutron energy, the curve would be roughly a straight line i.e., the probability of the reaction increases with *decreasing* velocity of the neutrons.

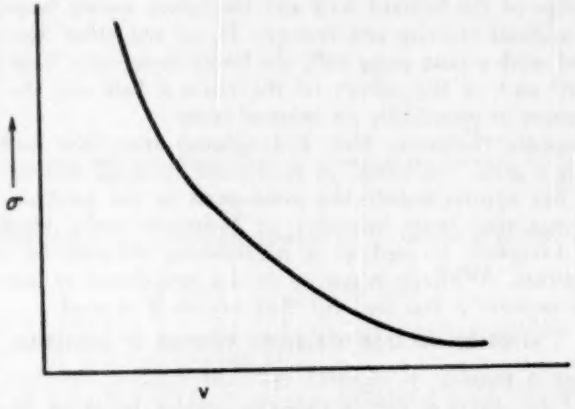


Fig. 2 Curve showing the relation between cross section and neutron velocity

This fact is explained when we recall that the de Broglie wave length associated with a neutron is *inversely* proportional to its velocity. Thus a slow neutron is not localized as much as a fast one, consequently it has a greater probability to strike a nucleus. Figure 2 is a curve which results from plotting the cross-section against the velocity of neutrons. For large values of velocity the cross-section approaches the geometrical cross-section of the nucleus.

Even this curve (Fig. 2) does not tell the complete story for as already explained in a previous chapter, it is found that if a beam of neutrons has a certain definite velocity (within rather a small range) the cross-section is much larger than would be expected from the curve shown in Fig. 2. This is due to the phenomenon of resonance.

EFFECT OF RESONANCE

Resonance alters the shape of the curve in Fig. 2 to something like that in Fig. 3. Peaks occur at various points on the curve where the resonances occur. The places on the velocity or energy scale where these points of resonance occur depend on the particular nucleus considered. The fact that cadmium has such an exceedingly high cross-section for slow neutrons may be explained by the presence of resonances at velocities corresponding to thermal energies.

The fact that slow neutrons have large cross sections make it desirable that sources of slow (thermal velocities) are available. When neutrons are ejected from nuclei as a result of nuclear reactions, they usually have high energies—energies large as compared to thermal energies. It is desirable, therefore, to "slow down" or moderate them. This can be done by making them have collisions with light nuclei—nuclei with approximately the same mass as the neutrons themselves. Energy transfer is most effective when

two colliding particles or bodies have the same masses. When a fast-moving billiard ball, for example, collides with a stationary one, the moving ball will transfer nearly all of its energy to the stationary ball—the latter will roll away, leaving the former at rest. This would not be the case if the billiard ball collided with a lead ball of equal size. The latter, having a much larger mass than the billiard ball would absorb very little of the kinetic energy of the billiard ball and the latter would bounce back with nearly its original velocity and energy. If, on the other hand the billiard ball collided with a ping pong ball, the latter being very light could absorb only a small part of the energy of the billiard ball and the billiard ball would continue at practically its original speed.

It is evident, therefore, that hydrogenous materials such as paraffin would make a good "colliding" or moderator material and such is the case. Hydrogen has approximately the same mass as the neutron and so, any material containing large amounts of hydrogen make good moderating materials. Graphite is used as a moderating material in many of the nuclear reactors. While it is not as good a moderator as paraffin, the loss by neutron capture is less and for that reason it is used.

TYPES OF NUCLEAR REACTIONS INDUCED BY NEUTRONS

There are a number of distinct types of nuclear reactions induced by neutrons. First, there is simple capture, usually followed by the emission of a gamma ray. In this case, the resulting nucleus is an isotope of one unit mass larger than the original nucleus. Second, there is the inelastic collision type of reaction in which the internal energy of the nucleus is changed. This reaction may be regarded as an absorption of the neutron by a nucleus and a subsequent re-emission of a neutron.

In a third type of reaction, the n.p. reaction, a neutron is absorbed and a proton is emitted. This reaction proceeds with fast neutrons, although a slow neutron reaction is known for nitrogen. In this case, the atomic number of the resulting nucleus is smaller than that of the bombarded nucleus.

Fourth, there is the neutron-alpha particle reaction in which an alpha particle is emitted. An example of this reaction is that obtained in bombarding lithium 6 with slow neutons: This is:

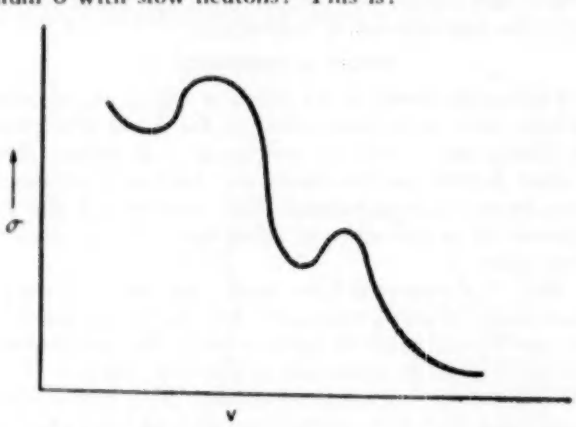


Fig. 3 Effect of resonance upon neutron cross section

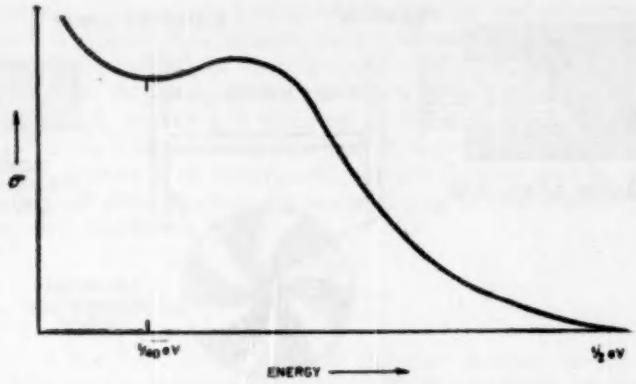


Fig. 4 Absorption cross section of cadmium as a function of neutron energy

$$Li^6 + n^1 \rightarrow He^4 + He^3$$

For heavier nuclei than Li^6, the alpha particle has to overcome a potential barrier, hence fast neutrons are required.

The fifth type of reaction is the n, 2n reaction where two neutrons are emitted. This also requires fast neutrons. Finally, for completeness, a sixth type of reaction may be mentioned; that involving elastic collisions in which the internal energy of the bombarded nucleus remains unchanged.

The last, of course, is the type of reaction involved in the "slowing up" of neutrons by a moderator such as paraffin. The collisions of the neutrons with the protons in the paraffin result in the initial energy of the neutron being divided up between the neutron and the proton. Thus, in successive collisions, the neutron loses energy until it finally winds up with thermal energies.

The collision cross-section and mean-free-path of the neutrons in paraffin vary a great deal with the energy of the neutrons. Where the neutron energy is above a Mv the cross-section is only a few barns, whereas for thermal neutrons it is 50 barns. At high energies the mean-free-path is a few *centimeters* while thermal neutrons have a mean-free-path of only a few millimeters.

NEUTRON ABSORPTION BY CADMIUM

As already mentioned, one very important substance in neutron physics is cadmium. Its absorption cross-section as a function of neutron energy is shown roughly in Fig. 4. Its strong absorption for thermal neutrons is due to a resonance lying very close to thermal energies. A few tenths of a millimeter of cadmium shielding is sufficient to remove all thermal neutrons from a distribution of neutrons.

It is of interest to describe the first experiments by which information on the cadmium absorption of neutrons was obtained at Columbia University. The experimental arrangement shown in Fig. 5 involved an arrangement based on Otto Sterns[1] apparatus for measuring atomic and molecular velocities. On the left side of Fig. 5, is what is known as a paraffin *howitzer*. It is a large block of paraffin which has embedded in it

[1] See Temperature and Nuclear Energy, ATOMICS, July 1949, page 8.

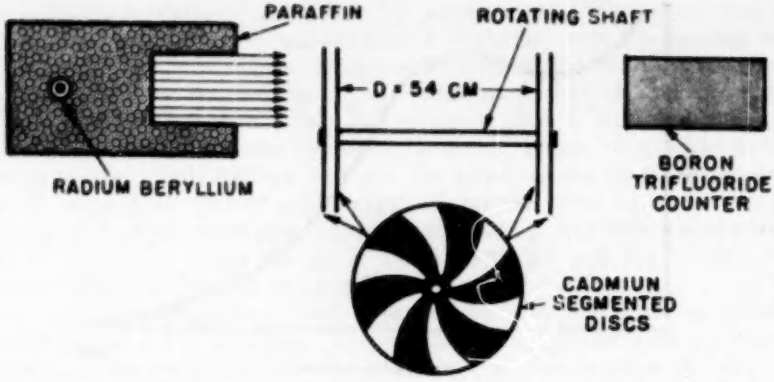


Fig. 5 Experimental arrangement used in determining cadmium absorption at Columbia University

a radium beryllium capsule[2] as shown. The neutrons emitted by the beryllium have to travel through the paraffin and are thus "slowed-up" to thermal velocities. The paraffin block, of course, emits slow neutrons from all its surfaces but there is a particularly strong and somewhat directed beam of slow neutrons issuing from the muzzle of the howitzer as shown by the arrows.

This neutron beam is directed through the velocity selector in the center of the diagram. This velocity selector is similar to that used by Otto Stern, the German physicist who first measured molecular velocities. This apparatus consists of two rotating discs mounted rigidly on a shaft, and two stationary discs—the latter located before the first and after the second of the rotating discs. On each of the four discs cadmium segments are located in such a way that there are on every disc, 50 cadmium segments and 50 segments free from cadmium. To the right of the velocity selector is located a boron trifluoride counter which detects the slow neutrons that have passed through the velocity selector.

In operation, the velocity selector is rotated at a speed, say of n revolu-

[2]See Nuclear Power Engineering, Part VI. Atomics, November 1949, pp 19-20.

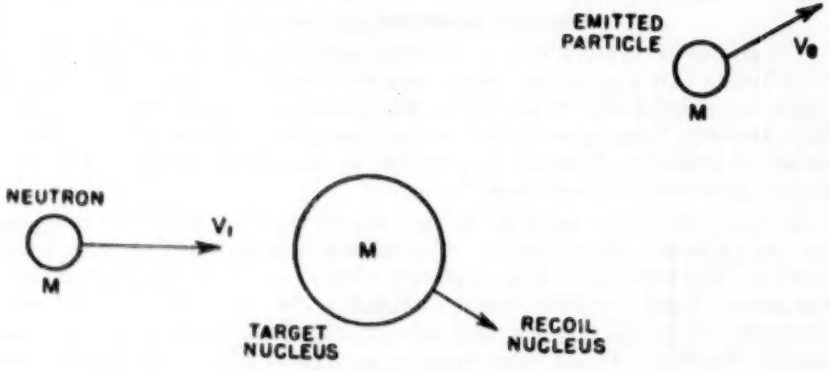


Fig. 6 Details of the collision process

tions per second. The cadmium strips of the rotating and adjacent stationary discs will at a given time overlap, so that the neutrons can pass through the cadmium-free parts of the disc. A short time later, however, the cadmium segments on the rotating and stationary discs will alternate so that no neutrons can get through. If the speed of the neutrons is such that they will find either the first or the second pair of rotating and stationary discs closed, then a minimum of transmitted neutron density will be observed. Assuming that all neutrons have the same velocity v, this minimum should occur when the relation

$$V = \frac{100\ n}{D}$$

is satisfied. It has been found that the neutrons emitted by the paraffin howitzer have an approximate velocity of 2500 meters per second. This value corresponds to thermal velocities.

THE GENERAL FEATURES OF COLLISIONS

In any collision process the *initial state* consists of a particle incident upon a target nucleus, and the *final state* consists of an ejected particle and a *recoil nucleus*. The process is illustrated in Fig. 6. For a given energy of the initial state there are a number of possible energies of the ejected particle as well as a number of possible energies of the recoil nucleus, provided these energies are consistent with energy conservation. If the magni-

INTERACTION OF NEUTRONS WITH SOME ELEMENTS

Isotope	Main Process	Thermal cross-section in Barns	Resonance cross-section in Barns	Fast cross-section in Barns	Remarks
H^1	Elastic scattering	20		1.7	Efficient neutron slow-up short diffusion of thermal neutrons
H^2	Elastic scattering	4		1.7	Good neutron energy degrader with no capture
L_1^6	Neutron absorbed alpha emitted	900		1-2	Good neutron shield and detector
B^{10}	Neutron absorbed alpha emitted	3000		1.5	Good neutron shield and detector
C^{12}	Elastic scattering	5			No capture
N^{14}	Elastic scattering and neutron absorbed proton emitted	10			
Fe	Elastic scattering and radiative capture	12			At least 1 gamma ray emitted per capture. Fe disturbs ionization chamber measurements by its gamma rays
Rh	Radiative capture	125		6000	Produces active isotopes
Cd	Radiative capture	2500			Produces stable isotopes

tude of the ejected particle and its duraction of motion are fixed, then momentum conservation fixes the momentum of the recoil and thereby the recoil's kinetic energy. The conservation of energy law then fixes the state of excitation of the recoil nucleus. Thus, specifying the momentum (magnitude and direction) of the ejected particle specifies the final state completely.

The detailed calculations used in determining the energy relations and the cross-section of nuclei under various conditions of elastic scattering, absorption, inelastic scattering, etc., will not be shown here, since they are easily available to those who need them,[3] and they would be too tedious for the general reader.

In concluding this chapter, we will, however, summarize briefly the interaction of neutrons with some of the elements. This is done in the accompanying table which, in part, was taken from H. A. Bethe, Rev. Mod. Physics, 9, 151 (1937).

[3] See Neutron Physics, by J. G. Beckerley, Document AECD—2664 published by the Technical Information Branch, Oak Ridge, Tenn.

Atomic Fissions

News From The Atomic World

Sixty-seven Patents Released by AEC

Descriptions of 67 patents owned by the U. S. Government and held by the Atomic Energy Commission have been transmitted to the U. S. Patent Office for registry and listing in the Official Register of Patents Available for Sale.

The descriptions were contained in a letter from Carroll L. Wilson, General Manager of the AEC, to T. T. Reynolds, Register of Patents. The transmittal was part of the Commission's program to make non-secret technological information available for use by industry.

This action of the AEC is in accord with the unanimous recommendation of the Commission Patent Advisory Panel that there be adopted a program of granting royalty-free, non-exclusive license to citizens on all inventions held by the AEC and which are not required for security reasons to remain classified. This program broadens a previous policy, initiated in 1946 by the Office of Scientific Research and Development and subsequently adopted by the AEC, of granting patent licenses only in the field of atomic energy instruments. The advisory panel consists of: William H. Davis of Davis, Hoxie & Faithful, New York, New York; Casper W. Ooms of Dawson, Ooms, Booth and Spangenberg, Chicago, Illinois; John W. Dienner of Brown, Jackson, Boettcher & Dienner, Chicago, Illinois; Hector M. Holmes of Fish, Richardson and Neave, Boston, Massachusetts, and H. Thomas Austern of Covington, Burling, Rublee, O'Brian and Shorb, Washington, D. C.

In the field of atomic energy and related fields, the AEC has acquired title to a large number of inventions made in the course of the work under its contracts and the contracts of its predecessor, the Manhattan Engineer District. Most of these inventions and applications for patents upon them

are held secret. However, from time to time, inventions and applications for patents are to be made public, with due regard for national security, in accord with the declassification procedures of the Commission.

Under the Atomic Energy Act, the Commission has responsibility for disseminating unclassified information to further scientific progress, and the enlargement of the scope of this program for licensing patents on inventions developed with public funds is regarded by the AEC as a step in conformance with the statutory directive.

R. S. Neblett Given Knolls Laboratory Post

Robert S. Neblett, assistant general manager of the General Electric Company's Nucleonics Department, has been appointed business and construction manager of the Knolls Atomic Power Laboratory.

This was announced by Dr. C. G. Suits, G-E vice president and director of research, head of the company's Research Laboratory, which operates the atomic power laboratory for the Atomic Energy Commission.

Mr. Neblett, in his new capacity, will handle all business and contractual relations between the laboratory and the AEC. Dr. Suits pointed out that these relations are becoming quite extensive, and will expand rapidly with the progress of new construction, such as the experimental atomic power plant at West Milton, N. Y.

AEC to Negotiate With Blaw-Knox for Materials Testing Reactor

The Atomic Energy Commission is negotiating with the Chemical Plants Division of the Blaw-Knox Construction Co. of Pittsburgh, Pa., for a contract covering architect-engineer services for the engineering design of a materials testing reactor. Selection of the Blaw-Knox Co. for these negotiations was announced by L. E. Johnston, AEC's manager of Idaho Operations.

Architect-engineer work to be performed will include the engineering design of the reactor and the preparation of detailed specifications and cost estimates.

Research, development and preliminary design of the reactor was begun in 1946 at the Oak Ridge National Laboratory, Oak Ridge, Tennessee, and for the past half year has been carried on jointly by the Oak Ridge Laboratory and the Argonne National Laboratory, Chicago, Illinois. The architect-engineer will work closely with these two laboratories.

Primary purpose of the new reactor will be to test various reactor construction materials under intense neutron bombardment. This will be of an intensity very much greater than any ever experienced before, even in the large production reactors at the Hanford Plutonium Works, Richland, Washington.

"The materials testing reactor," Dr. Lawrence R. Hafstad, Director of the AEC's Division of Reactor Development, has said "will provide the Commission with a powerful new tool for the furtherance of the whole reactor development program. Principally, it will be a means for testing fuel and structural materials under the severe conditions of temperature and radiation which will be encountered in the power reactors of the future. The new reactor will therefore play a vital part in the development

of atomic plants for the production of power and atomic engines for the propulsion of ships and possibly aircraft."

The new reactor will also provide an intense source of neutrons for use in experiments in neuclear physics.

Millikan Pessimistic Concerning Use of Atomic Energy for Power

In an address which Robert A. Millikan delivered before the Institute of Radio Engineers, he felt that there was not enough uranium in the world to permit its use for the development of power. "After fifty years of search," he said, "by government bureaus of mines and private individuals and companies, there are now but two places in the world—Canada and the Belgian Congo—from which uranium ores can be obtained in considerable commercial quantities, and two more places—Colorado and Joachimsthal—where smaller deposits exist. In view of that record I do not anticipate that either intelligent governments or intelligent individuals will use uranium for any major fuel or power purposes. It is too valuable a material for scientific purposes, for public health purposes and for such industrial purposes as require small quantities to be wasted on major power projects so fully provided for by the inexhaustible supplies of solar energy, past or present. According to the Atomic Energy Commission, uranium and thorium *are the only elements which have a chance in disintegrating of releasing atomic packing-fraction energy*, and there is no available energy save packing fraction energy. Because of the extreme rarity of these elements wisdom calls for their conservation rather than their use for fuel or power."

May Have to Spend 200 Million Dollars in Developing Atomic Power

The United States will probably have to spend about $200 million in building a number of successive experimental atomic power plants before it will be possible to judge the economic possibilities of atomic energy, according to C. G. Suits, vice president and director of research for the General Electric Co.

Addressing the National Academy of Sciences at Rochester, N. Y. on Oct. 25, he pointed out that there is no present assurance that even after such an expenditure the final economic result will be successful, because of the many unanswered technical questions. If a profitable atomic industry does develop, he added, it will be decades away. Dr. Suits directs the G-E Research Laboratory in Schenectady, under which the Knolls Atomic Power Laboratory of the AEC operates.

He declared that atomic research could not be adequately supported by private capital, and that government resources were necessary. He pointed out that the military implications of atomic energy made government control doubly necessary. Speaking of the long length of time required in the application of atomic energy, Dr. Suits recalled that the first oil well in the U. S. was drilled in 1859, but it was more than 50 years later before oil became a significant source of power in this country.

Real development of the petroleum industry, he asserted, required the invention of the internal combustion engine, and the solution of many scientific and technical problems posed by this engine. Then its progeny—the automobile, airplane, diesel engine, as well as modern efficient methods

of finding and refining petroleum—all had to be developed and their problems solved before the petroleum industry reached real significance as a source of power.

"The development of atomic energy as a significant power source," Dr. Suits declared, "awaits the solution of a similarly imposing array of technical problems and will require a correspondingly long period of time."

He pointed out, however, that there are important differences between petroleum and atomic energy. The former, like most successful industries, was able to begin on a small scale. The first oil from the first well could be sold at $20 a barrel, and the profits used to drill more wells, from which more oil could be sold, thus gradually expanding the industry.

With atomic energy such development cannot take place, he said. The nuclear fission chain reaction which is the origin of atomic energy will not work on a miniature scale. Thus, he stated, "there is no prospect that the test tube and pilot plant stage of development, during which practically all of the technical problems of ordinary industrial processes are solved, can be employed." Even the very first plants, such as the one now being built by General Electric for the AEC at West Milton, N. Y., must be large and costly.

The necessity for shielding the atomic reactor or "furnace" so that radiations produced will not be hazardous, he stated, also increases the cost in such a way that even if small atomic plants would operate, their heavy radiation shields would make them large and costly. Thus there must be a succession of experimental plants, each larger and more costly than its predecessor, before atomic power can be made practicable.

AEC Approves Export of X-Ray Generator to England

The U. S. Atomic Energy Commission announced recently that it has approved the export of a two-million-volt electrostatic X-ray generator to the Westminster Hospital, St. Johns Gardens, London, England, for use in the treatment of cancer.

The X-ray generator will be manufactured by the High Voltage Engineering Corporation of Cambridge, Massachusetts. It is the fourth such machine approved for export to England for radiation therapeutic uses during the past two years.

The AEC considers requests for export licenses for certain high-energy X-ray generators and particle accelerators under a regulation issued by the Commission in November, 1947. The following considerations are taken into account in the award of each license:

1. The manufacture of the equipment cannot interfere with the meeting of domestic requirements for similar apparatus.

2. Export of the equipment cannot be objectionable for reasons of national security.

Materials Testing Reactor To Cost $25,000,000

The scientific design of the materials testing reactor has been developed in a cooperative effort by the Oak Ridge National Laboratory and the Argonne National Laboratory. A $1,870,000 contract for detailed engineering design work on the reactor was signed last September with the Blaw-Knox Construction Co. of Pittsburgh, Pennsylvania. Design work is underway and construction is expected to begin by next spring.

The primary purpose of the materials testing reactor will be to test under conditions of severe neutron bombardment the materials which may be used in future reactor construction. The materials to be tested will be contained in test pockets. The neutron bombardment to which they will be subjected will be of an intensity very much greater than any ever experienced before. Since the power reactors of the future will be operated at greater neutron intensities than those in operation today, it is important to learn in advance how various materials that might be used in the structures, cooling systems or shields will react under these unusual conditions.

The materials testing reactor is of particular interest in the development of reactors for the propulsion of aircraft, since it points in the direction of compact, high radiation density reactors which must ultimately be developed if aircraft are ever to be propelled by atomic energy. On the basis of rough preliminary estimates, it is expected that the reactor will cost about $25,000,000.

AEC Announces Reactor Development Training School

Advanced training in the field of reactor development will be given government and industrial scientists and engineers at a newly established Atomic Energy Commission Reactor Development Training School at the Oak Ridge National Laboratory.

The emphasis on the new school will be to supply as quickly as possible scientists and engineers with formal training in reactor development. The students will fall into three categories:

(*a*) Engineers from industrial organizations who will remain on their companies' payrolls while attending the training school.

(*b*) Employees of other atomic energy laboratories or other government agencies detailed to Oak Ridge for training.

(*c*) Recent college graduates hired by Oak Ridge National Laboratory who will be trained as regular employees and will then be available for transfer to reactor groups throughout the atomic energy program.

Present plans call for about 60 students to be trained at one time, about 30 students in categories (*a*) and (*b*) and an additional 30 in category (*c*). The school will operate continuously. All students will be required to have complete security investigation and clearance and the lectures and study material will be classified. Selection will be made by the Commission from qualified applicants on the basis of the need of the organization with whom its applicant is affiliated for personnel trained in reactor development, its potential contribution of the applicant to the AEC programs, and his academic record.

The shortage of trained men in the reactor development field has seriously hampered the national program for design and construction of new types of nuclear reactors. Reactors are the machines used for production of atomic energy and materials for atomic weapons.

Industrial participation is an important part of the training program since many American industrial concerns are working under AEC contracts on one or more phases of reactor development. In addition, many industrial companies of potential value to the national reactor development program have been unable to undertake work in the field because of their lack of men with the necessary training.

Plans for industrial participation are in accord with proposals made to the Commission by professional and engineering groups to provide opportunities for selected industrial organizations to send working-level engineers to atomic energy installations for firsthand experience and training.

The Oak Ridge National Laboratory is well located for such a training school. The Laboratory has also had considerable experience in operating training schools. In 1946-47 the Oak Ridge Training School—dubbed "The Clinch College of Nuclear Knowledge"—was run to provide post-doctorate training in the theoretical aspects of the nuclear sciences. Currently the Laboratory is operating an educational program in reactor physics and reactor technology for its own employees.

Dr. F. C. Von der Lage, former director of the training division of the Oak Ridge National Laboratory has been named director of the Reactor Development Training School.

New Series of Tests of Atomic Weapons Is Planned

The Department of Defense and the Atomic Energy Commission have advised the President that a new series of tests of atomic weapons is planned at the Commission's Proving Ground at Eniwetok Atoll in the Marshall Islands.

Full security restrictions as required by the Atomic Energy Act apply to all aspects of test preparations, including the time of the tests.

As in past atomic weapons test projects, the field operations will be carried out by a Joint Task Force, composed of personnel of Army, Navy, Air Force, and the Atomic Energy Commission. Lieut. Gen. Elwood R. Quesada, USAF, will command Joint Task Force-3, which has been formed to carry out the new test program. General Quesada will have as deputies, Brig. Gen. Herbert Loper, Army, Rear Admiral Tom B. Hill, Navy, and Dr. Alvin C. Graves of the Los Alamos Scientific Laboratory. Chief of Staff is Brig. Gen. John K. Gerhart, USAF.

The Commission recently announced a contract with Holmes and Narver, Los Angeles engineering and construction firm, for maintenance and improvement of facilities at the Eniwetok Proving Ground. Military and Naval units participating in the current work at the Proving Ground will be a part of Joint Task Force-3.

New Books on Atomics

Atomics For the Millions. By Dr. Maxwell Leigh Eidinoff and Hyman Ruchlis. First edition, 281 pages, 6¼ by 9¼, illustrated, cloth. Whittlesey House, McGraw-Hill Book Co., New York, N. Y., 1949. Price $3.50

This is a book intended, not for engineers or those who have a basic understanding of physics, but for laymen; those to whom even the simplest elements of chemistry have to be explained. Stripped of unnecessary scientific terminology, and with more than 100 amusing graphic illustrations it gives a comprehensive picture of atomic energy and its future potentialities. It traces the development of atomic energy from its first beginnings in Greek theory, through the fact of nuclear fission, to a preview of the coming applications of radioactive materials to medicine, and the second industrial revolution. Special emphasis is placed on the highly intensified pace of the five years of war, and the tremendous achievement of that relatively small group of scientists who worked against time to the end of the war. The preview of the future is very interest-

ing, considering such matters as interplanetary travel, use of radioactive isotopes in medicine and industry, and atomic power.

The illustrations in this book are worthy of special mention. They were drawn by Maurice Sendak. Essentially graphical in character, many of the pictures are personified by the introduction of little figures, people as well as animated nuclear particles.

Dr. Eidinoff at present is a member of the Chemistry Department of Queens College. A graduate of Brooklyn College, he was research supervisor at Columbia University Site of the Manhattan project, Research group leader at the Metallurgical Laboratory of the Manhattan project at Chicago University, and Department head at the Kellex Company site of the Manhattan project.

Hyman Ruchlis is a graduate of Brooklyn College. He has spent a number of years as a teacher of physics in high school. At present, he is Vice-President of the Physics Club of New York and has done extensive work on the improvement of existing science sources.

The book has a very interesting introduction by Dr. Harold Urey.

Seventh Semiannual Report of the Atomic Energy Commission. 228 pages, 6 by 9¼ in., paper cover. United States Printing Office, Washington, D. C., January 1950.

As pointed out by AEC Chairman, David Lilienthal at a press conference at the time of the release of this report, the most remarkable thing about the report is that it was published at all. "In view of the difficulties of publicly issuing documents that might throw any light on this undertaking, to be able to get a report of this size seems to be quite an achievement." Continuing his remarks, Mr. Lilienthal said, "I, myself, happen to think—and this is just wholly a voluntary remark—that the boys who did this did an extraordinary good job of technical reporting. I think there are here (in the report) sentences that are graphic and solid, and a style of reporting technical matters in a field where it is difficult, that I found, myself, very helpful. I think it is an attractive thing to read. . . . I need hardly say that I didn't do any of the writing."

Mr. Lilienthal is entirely correct. This report is not only an extremely well-written treatise but, within the framework of rigid security regulations, presents considerable new information regarding atomic energy research. Most interesting to those who have been intrigued by the recent announcement of the plan to construct the hydrogen bomb, is the description of researches at the Argonne and other AEC laboratories on the three isotopes of hydrogen.

The report is presented in two parts. Part one deals with the activities and developments in the atomic energy program during 1949 while Part 2 is concerned with research in physical sciences and progress in atomic energy.

Part 1 includes sections on production of materials, military applications, reactor development, biology and medicine, finance, AEC and civil defense planning, informational and educational services, orgaization and personnel, and finally, security.

Part 2 involves the objectives of the AEC research program; Men, machines, and laboratories for physical research; atomic energy research; application of the results of research; research management; and, finally, the atomic energy laboratories.

Everyone seriously interested in developments in atomic energy, professionally or as a layman, should read this splendid report.

Any book described in this department may be purchased from the Book Department, ATOMICS, Technical Publishing Company, 53 W. Jackson Blvd., Chicago 4, Illinois

The Atomics Bookshelf

Introduction to Radiochemistry. By Gerhart Friedlander and Joseph W. Kennedy. John Wiley & Sons, Inc. $5.00

An excellent, up-to-date book describing the nature and applications of radioactivity without assuming previous knowledge of nuclear physics. It begins with a brief discussion of the historical background which is used as an introduction to the early chapters on descriptive information about atomic nuclei, nuclear reactions, and the apparatus used for the acceleration of nuclear projectiles. Later chapters discuss all aspects of nuclear phenomena.

Radioactive Tracer Techniques. By Geo. K. Schweitzer and Ira B. Whitney. D. Van Nostrand Co. $3.85

A useful manual designed to serve as a guide for laboratory work and instruction in the use of radioactive tracers. It should be of value to all who may have use for radioactive isotopes as tracers in industrial or medical applications.

The Atomic Story. By John W. Campbell. Henry Holt & Co., $3.00

By all odds the best and most interesting book on atomic energy for the layman. Written by a man who possesses the unique combination of writing ability and technical knowledge, it is first of all a story, not a treatise. At the same time it is accurate. It is the most important story of our time told in simple language by a man who has spent many years in the field of science fiction. He is the Editor of Astounding Science Fiction.

The Strange Story of the Quantum. By Banesh Hoffman. Harper & Brothers, $3.00

Easily the best account of the growth of the ideas underlying our present knowledge of atomic structure, prepared for the reader not especially trained in nuclear physics. It has taken one of the most abstruse and difficult questions—just how matter and energy are put together—and made it readable and understandable as it can be.

The Science and Engineering of Nuclear Power. Two Volumes. Edited by Clark Goodman. Addison Wesley Press, Inc., $7.50 each

These two volumes contain the essentials of a series of seminars initiated at MIT in October 1946. They provide, by far, the most valuable and usable technical material for the engineer available today. Their objective is to present the fundamentals of chain reacting systems in terms that are understandable to engineers interested in the industrial applications of nuclear energy.

Atomic Energy. By Karl K. Darrow. John Wiley & Sons, Inc., $2.00

The exciting story of the development of nuclear physics—a story climaxed by the reality of atomic energy and the atomic bomb. Told by an expert who can speak the layman's language.

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